Presented to Earth System Science and Applications Advisory Committee

Science Research in ESE: Strategy Development and Program Implementation

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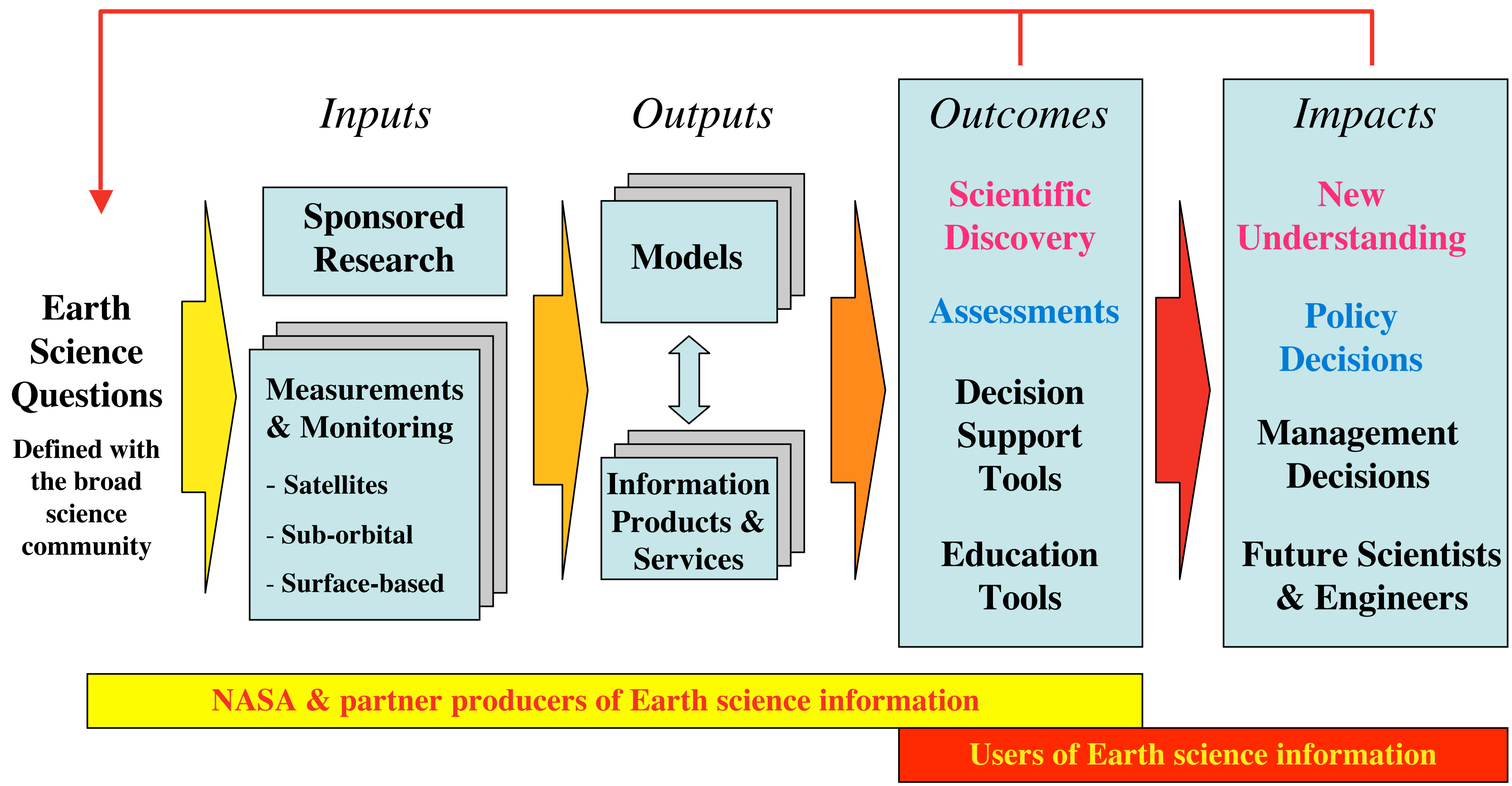
Overview of Talk

- ESE Research Strategy
  - Goals of Research Program
  - Prioritization Criteria
  - Research Questions Driving Program
- Implementation via focus areas
  - Roadmaps to the future
  - Maintaining roadmaps
- Working with the community
  - Past and Present Ties
  - Future Expanded Approach

From Science to Societal Impact (& Back Again)



Research

- Progress:
  - Defined the questions appropriate for NASA and implementation roadmaps to answer them
  - Moving to identify the climate data records for which we should take responsibility
    - Moving from mission science teams to measurement-focused teams that span generations of satellite missions
  - Investing in data assimilation and modeling to enable the use of new data types to improve predictions and process understanding

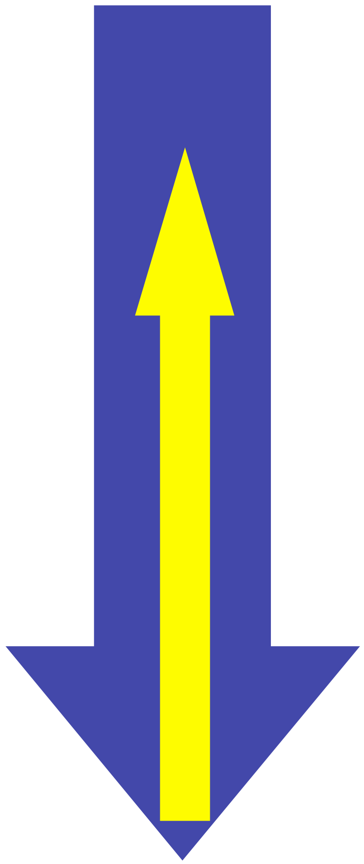
- Challenges:
  - Continued & expanded community involvement is essential
  - End-to-end management
  - Competition vs. stability

Goals of Research Program

- Generation of Scientific Knowledge
- Generation of Products for Policy and Decision Makers
  - Quantitative Scientific Data Sets
    - Climatology and Integrated Data Sets for Scientific Study
    - Trends (esp. to get at statistical significance of long-term trends)
  - Model Predictions
    - Initialized and Verified by available data
    - Sufficiently complex to be useful over period of application
    - Resolution appropriate to scales being addressed by model
    - Run in sufficient time and number to be broadly useful
- Infusion of New Techniques and Approaches into Applications Program
- Development and Evaluation of Techniques for Advancement through Technology Program
- Providing Research Experiences for Training Next Generation of Scientists
- Providing Leadership for Development of Future National and International Earth Science Research Programs

Establishing Priorities

Science Priority Criteria



Science Return

Benefit to Society

Mandated Program

Appropriate for NASA

Partnership Opportunity*

Technology Readiness

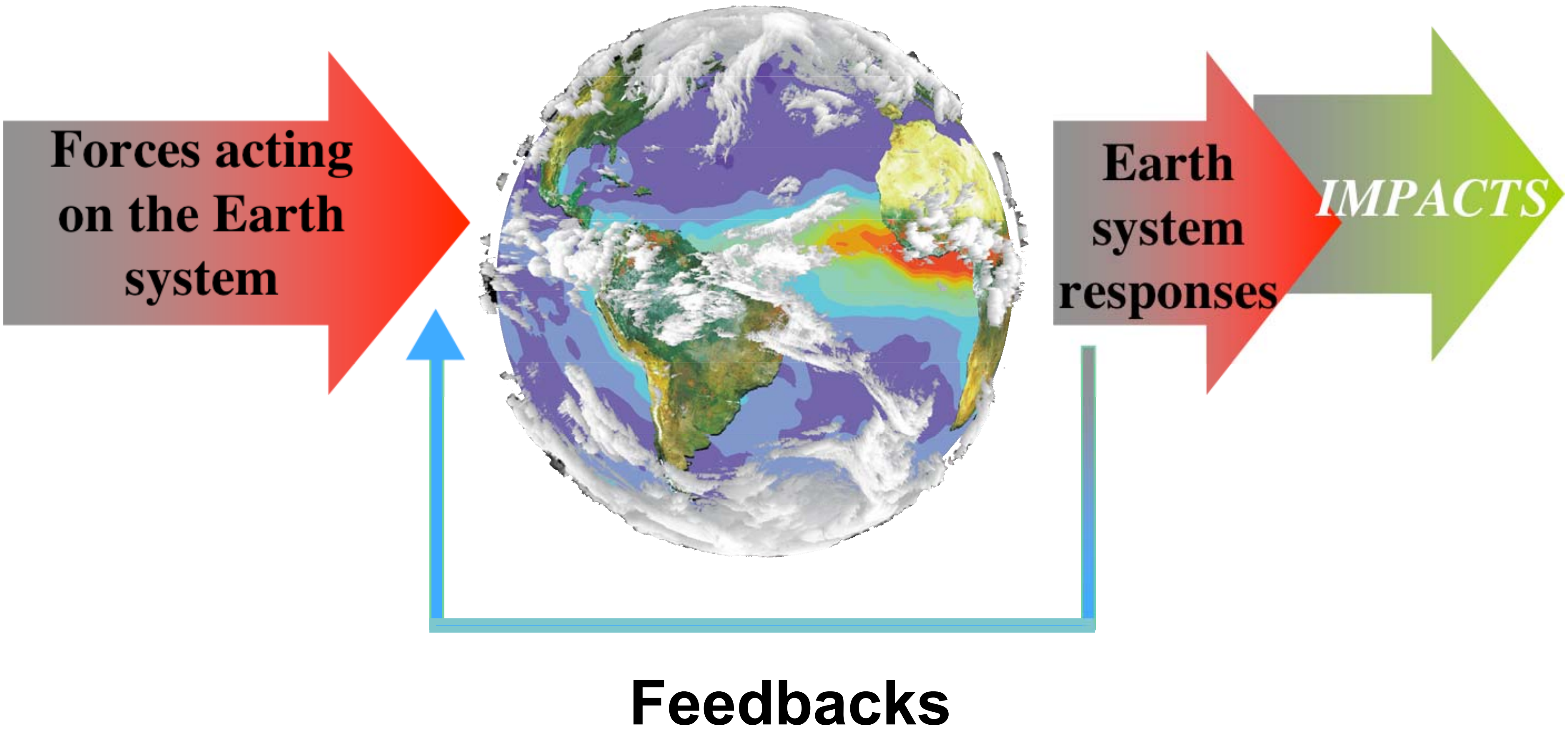
Program Balance

Cost/Budget Context

Implementation Priority Criteria

* Includes potential for handoff to operational systems

Earth as a Dynamic System



Science Questions from the Research Strategy (old)

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather forecasting improvement?
Global ocean circulation varying?	Changes in land cover & land use?	Ecosystem responses & affects on global carbon cycle?	Consequences in land cover & land use?	Transient climate variations?
Global ecosystems changing?	Surface transformation?	Changes in global ocean circulation?	Coastal region change?	Trends in long-term climate?
Stratospheric ozone changing?		Stratospheric trace constituent responses?		Future atmospheric chemical impacts?
Ice cover mass changing?		Sea level affected by climate change?		Future concentrations of carbon dioxide and methane?
Motions of Earth & interior processes?		Pollution effects?		

Revising Set of Science Questions

- Process to Revise Science Questions involved program managers, some members from prior ESSAAC
- General discussion held at previous ESSAAC meeting
- Subsequent iteration led to set of questions distributed as part of draft strategic plan
- Only a few changes, but these are deliberate and significant
  - Rewording of some questions to sharpen and focus
  - "Swapping" solid earth questions in variability and forcing to better reflect "solid earth" point of view as defined by SESWG
  - Moving "air quality" question from response to consequences
  - Combining two climate prediction questions into a single one (integrating seasonal-to-interannual and long-term)
  - Adding prediction questions for water cycle and earth surface, so now have a prediction question for each science focus area

Science Questions from the Research Strategy (new)

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather forecasting improvement?
Global ocean circulation varying?	Changes in land cover & land use?	Ecosystems, land cover & biogeochemical cycles?	Consequences of land cover & land use change?	Improve prediction of climate variability & change?
Global ecosystems changing?	Motions of the Earth & Earth's interior?	Changes in global ocean circulation?	Coastal region impacts?	Ozone, climate & air quality impacts of atmospheric composition?
Atmospheric composition changing?		Atmospheric trace constituents responses?	Regional air quality impacts?	Carbon cycle & ecosystem change?
Ice cover mass changing?		Sea level affected by Earth system change?		Change in water cycle dynamics?
Earth surface transformation?				Predict & mitigate natural hazards from Earth surface change?

Updating Research Strategy

- Revised Set of Questions is Prerequisite to Initiating Update
- External and Internal Context require revisions
  - Agency vision and mission
  - CCSP instead of USGCRP
  - Technology tie, including NASA visions, and CCTP
- Updating tables of observational products
- Creating tables of modeling products
  - Note prioritization for modeling effort and relationship to computing environment is key issue for near-term effort

Modeling in NASA/ESE

- What we are doing:
  - Long-term climate modeling
  - Seasonal-to-interannual climate modeling
  - Weather modeling
  - Ocean data assimilation
  - Earthquake and geodynamo simulation
- What we want to do:
  - Single modeling framework for weather and climate
  - Models that utilize new types of NASA data for initialization and evaluation
  - Data assimilation and reanalysis that can uniquely be done by NASA
  - High resolution models that match the resolution of NASA data sets
- What it takes to get there:
  - Hardware- we are currently limited by our computing power and computer architecture
  - Software and system Engineering – putting the SW and HW together
  - Data management and data mining – thinning the vast amount is the key
  - People – computational scientists, system engineering and Earth system modelers work together to achieve enterprise goals

Modeling at NASA – Future strategies

- Enhance modeling to capitalize on NASA's unprecedented new capabilities in space-based Earth observation
  - Utilize new types of NASA data for initialization and evaluation of NASA models and to improve predictions
  - Create assimilated new data sets for scientific use, including reanalysis when it can uniquely be done by NASA
  - Increase resolution of models to approach or match resolution of NASA data
  - Create a single modeling environment and strategy for weather and climate predictions

The return on society's investment in space-based observations will to a significant extent come from our ability to improve predictions of climate, weather and natural hazards

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Organizing Earth System Science Research

- Earth system is sufficiently complex that implementing program requires it be “taken apart” to be “put back together”
  - No unique way to do this
- Earth system is sufficiently interlinked that no way of taking it apart doesn’t separate tightly linked processes
  - Some ways clearly don’t make sense (e.g., geographically)
  - Some ways may seem convenient at first, but cause difficulties (e.g., by earth system component)
- However one does this, care is needed to assure interdisciplinary science is addressed

Organizing Earth System Science Research

- Organizing structure can take advantage of unique elements of Earth system
  - Presence of carbon-based life
  - Presence of water in multiple interacting phases
  - Atmosphere and ocean that redistribute heat making most of planet habitable
  - Oxidizing and protecting atmosphere
  - Dynamic environment with lots of short-term fluctuations in environmental conditions
  - Dynamic surface made up of water and land

Focus Areas for ESE Research

- Build Program around 6 interdisciplinary focus areas
  - Carbon Cycle and Ecosystems
  - Global Water and Energy Cycle
  - Climate Variability and Change
  - Atmospheric Composition
  - Weather
  - Earth Surface and Interior

Science Questions and Focus Areas

Variability	Forcing	Response	Consequence	Prediction
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Earth surface transformation?				Predict & mitigate natural hazards from Earth surface change?

Climate Variability and Change
Atmospheric Composition
Carbon Cycle and Ecosystems
Weather
Water and Energy Cycle
Earth Surface and Interior

“Putting Pieces Back Together”

- Ex. - Future concentrations of atmospheric methane (only a part of carbon cycle):
  - Sources:
    - Emission estimates based on knowledge of
      - Land cover use and associated emissions (e.g., landfills, rice cultivation)
      - Biogeochemistry of emitting species (plant, animal)
      - Fires
      - Pollution
    - Climate feedback associated with loss of “stored methane”
  - Sinks:
    - Reaction with hydroxyl
  - Transport:
    - Atmospheric dynamics

Thus, see multiple focus areas must be addressed in an integrated sense to get answer to question

Managing to Focus Areas

- ESE is working towards trying to “manage to focus areas”
- This means having a mechanism to integrate all key elements of program
  - Research
  - Production of climate data records
  - Technology development
  - Mission science teams and data analysis
  - Development programs
  - Operating missions
  - Applications
- Focus area thus provides end-to-end management
- Focus area needs to address issues of NASA capability and balance between competition and stability
  - This is of particular concern for data set preparation and modeling activities now
  - Issue of climate data records is a particularly important one, that can draw on some successful examples, but becomes more complex in future

Managing to Focus Areas, cont.

- Focus area would be responsible to develop and maintain *roadmaps* and implementation plans
- Initial trade space for budgeting would be within focus area
- Research division is being looked to for providing leadership in this transition
- Actual mechanism for doing this and personnel implications are currently being worked

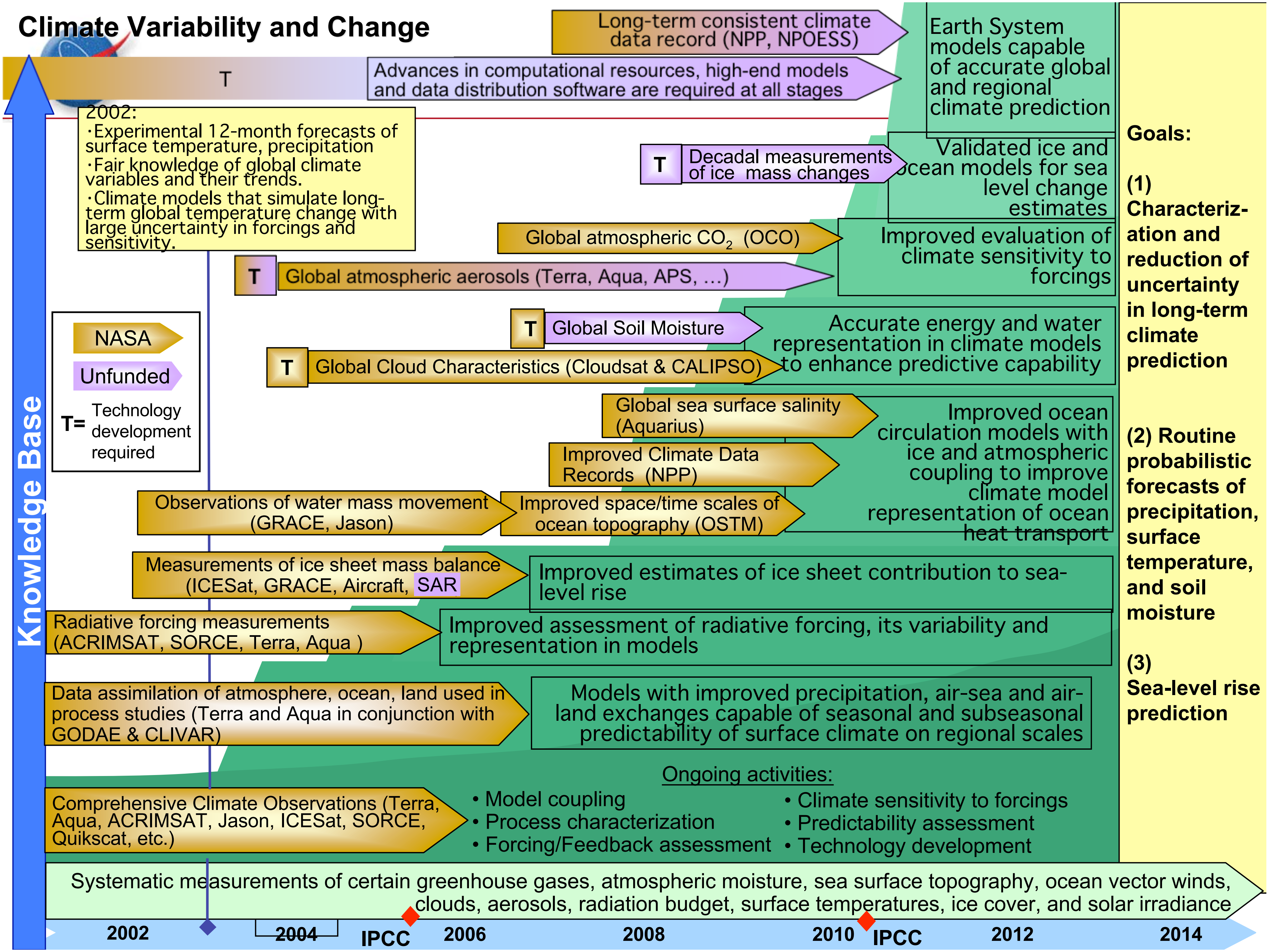
The Roadmapping Challenge

- Need to be able to demonstrate goal at end of reasonable time interval (e.g., decade)
  - Scientific knowledge
  - Societally relevant products and their impacts
- Need to demonstrate connection between where we are now and where we expect to be
- Need to show that different components of ESE research are integrated into uniform whole
- Need to demonstrate availability of intermediate milestones (focusing on "outcomes" and not "outputs")
- Need to show interconnectedness of research activities (no "stovepipies")
- Need to give sense of relationship of NASA activities to those of our partners

Roadmap Organizing Principles

- Start showing sense of where we are and give vision of where we intend to be
- Indicate "base" of activities that supports other activities, esp. systematic measurements and partner-supplied information
- Provide sense of improved knowledge based on continuing research based on current information and capability
- Show inputs and corresponding outcomes based on current investments for present and near-term inputs
- Indicate longer lead term items that require technology development
- Provide some sense of what's likely to be doable within present program and what is not
- Roadmaps should have "levels" of detail to allow interested user to "dig in" without distracting those needing broad view

Climate Variability and Change



Roadmapping Experience

- Roadmaps must be used in consideration of relationships between each other and overall priorities
- Roadmaps have become important tool for describing our program
  - They have become part of Integrated Budget and Performance Document
- Roll-up of elements has been very useful - e.g., technology
- Roadmaps need to be regularly "maintained" in concert with community
- Roadmaps are not the end - must get to implementation plans based on roadmaps
  - This is also best done in concert with community
  - Need to update periodically
- We see ESSAAC as key representative of community and a primary mechanism for interfacing with it

NASA / CCSP Alignment

NASA Science Focus Areas

- Climate Variability & Change
- Atmospheric Composition
- Carbon Cycle & Ecosystems
- Water & Energy Cycle
- Weather
- Earth Surface & Interior

CCSP Research Elements

- Climate Variability & Change
- Atmospheric Composition
- Global Carbon Cycle
- Land Use / Land Cover Change
- Ecosystems
- Global Water Cycle
- Human Contributions & Responses

- Differences between NASA science focus areas and CCSP research elements reflect broader ESE mandate (weather, earth surface)
- ESE integrates carbon cycle and ecosystems because of our large scale focus
- ESE does not separate land cover/land use change, instead applying it to relevant focus areas (esp. carbon, water)

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NASA-Community Relationships

- NASA draws on strong and growing Earth Science Research Community
- NASA centers/JPL, universities, other government agencies, private/non-profit entities, and foreign agencies all play important role in ESE
- Research community writes proposals and actively supports review process
- NASA draws from (and contributes to) community through multiple mechanisms (besides ESSAAC)
  - NRC reports and panels
  - Professional societies (e.g., AGU, AMS)
  - Planning activities (e.g., carbon, SESWG, WATeR)
  - International peer-led activities (IGBP, WCRP and their component projects)

ESE Research Solicitations

- ESE regularly releases solicitations for scientific research
- Trend has been towards fewer, larger, and more integrated solicitations (esp. science/mission, but also discipline/earth system component)
  - Oceans, ice, and climate
  - Solid Earth and Natural Hazards
  - LBA-Eco Phase II
  - Atmospheric composition (including SOLVE II, SOSST)
  - Precipitation science
  - Radiation science, tropospheric chemistry, and climate
  - Interdisciplinary science
  - EOS Science - algorithm refinement and science data analysis
  - NPP Science Team
- Response to solicitations has been significant and suggests we think about alternate approaches (esp. 2-step)

Recent Research Solicitation Statistics

Solicitation	# Rec'd	# Funded	% Funded				
			NASA	Univ.	OG	Priv.	For.
Oceans, Ice, Climate	276	70	21	61	10	6	1
New Investigator Program*	132	26	23	73	0	4	0
Solid Earth/Natural Hazards@	243	87	29	57	6	6	2
LBA Ecology - Phase II	101	35	11	69	9	11	0
Atmospheric Composition	163	92	43	32	5	15	4
Precipitation Science	173						
Radiation Science	275						
Interdisciplinary Science	346						
EOS Algorithm Refinement/ Science Data Analysis	565						
NPP Science Team	68						

* Managed by Applications division (YO)

@ Includes both Research and Applications Components

Working with the Community

- Community must be brought into role of helping to maintain roadmaps
- ESSAAC members can play significant role in helping us to design and implement this interaction
- Focus area oriented workshops can be held
  - Led by ESSAAC members with community member(s)
  - Held geographically distributed
  - Charge is to maintain roadmap and initiate development and complete review of implementation plan
  - Time scale can be more frequent for roadmap maintenance than for implementation plan cycle
- Periodically would need community-wide workshop to review rodmaps for gaps, consistency, etc.

Working with the Community, cont.

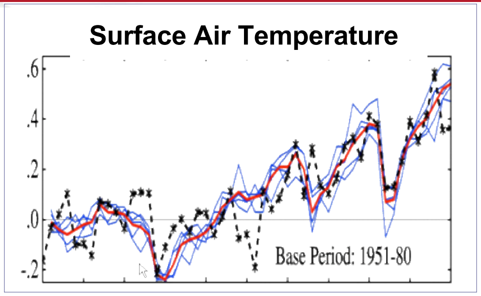
- Other community interactions must be carried out on periodic basis
  - Focused presentation of results in specific areas (e.g., addressing Earth system components)
  - Sharing information about NASA programs, projects, and plans
    - Note EOS IWG meeting has served this role in past, but requires evolution for current environment
    - Focused efforts to consider progress relative to specific activities needed to guide efforts in future, for ex.
    - Future remote sensing techniques and instrumentation
    - Field campaigns
    - Model-model and model-data intercomparisons
  - With educational and research community to encourage broader participation in ESE programs
- NASA needs to balance "NASA-led" interactions with those organized more broadly - esp. by relevent professional societies (e.g., AGU, AMS)

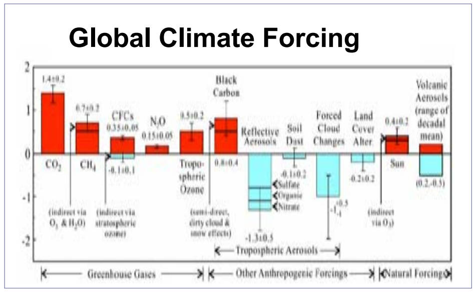
Summary

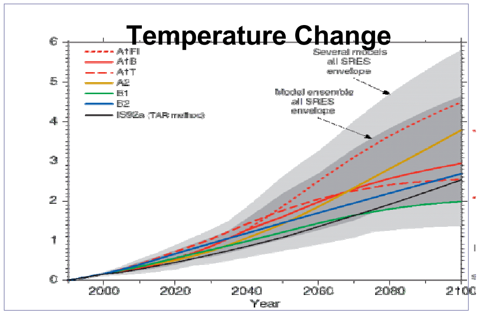
- Prioritization criteria identified in 2000 ESE Research Strategy are still valid in today's external and internal contexts
- Research questions have been updated for current strategic plan cycle
- Six scientific focus areas can be used to represent program, but require careful implementation to assure appropriate treatment of interdisciplinary science
- ESE is transitioning towards "managing to focus areas" in order to better implement "end-to-end" approach, including construction of climate data records
- Focus area roadmaps are key to articulating program direction and are becoming useful and understood but must be maintained
- Solicitations provide opportunities for community to participate in research program, and reflect integrated approach to program management
- Active record of community involvement should be expanded for maintaining roadmaps, developing implementation plans, and making plans for the future

Climate Variability and Change

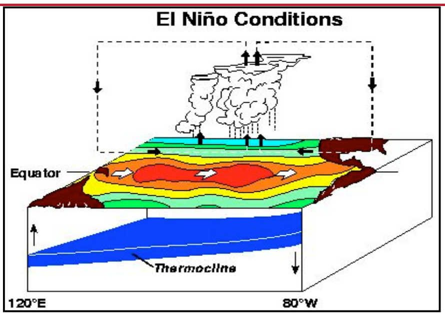
Forward

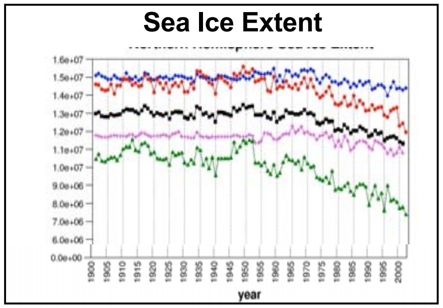


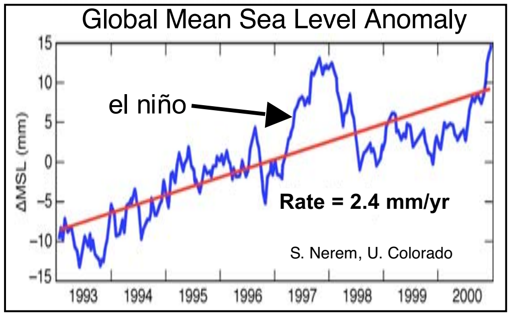




- How is global ocean circulation varying on interannual, decadal, and longer time scales?
- What changes are occurring in the mass of the Earth's ice cover?
- How can climate variations induce changes in the global ocean circulation?
- How is global sea level affected by natural variability and human-induced change in the Earth system?
- How can predictions of climate variability and change be improved?







Climate change is one of the major paradigms guiding Earth System Science today. NASA is at the forefront of quantifying forcings and feedbacks of recent and future climate change. Our comprehensive end-to-end program goes from global high-resolution observations to data assimilation and model predictions.

Anticipated Progress in Answering the Questions: Climate Variability and Change

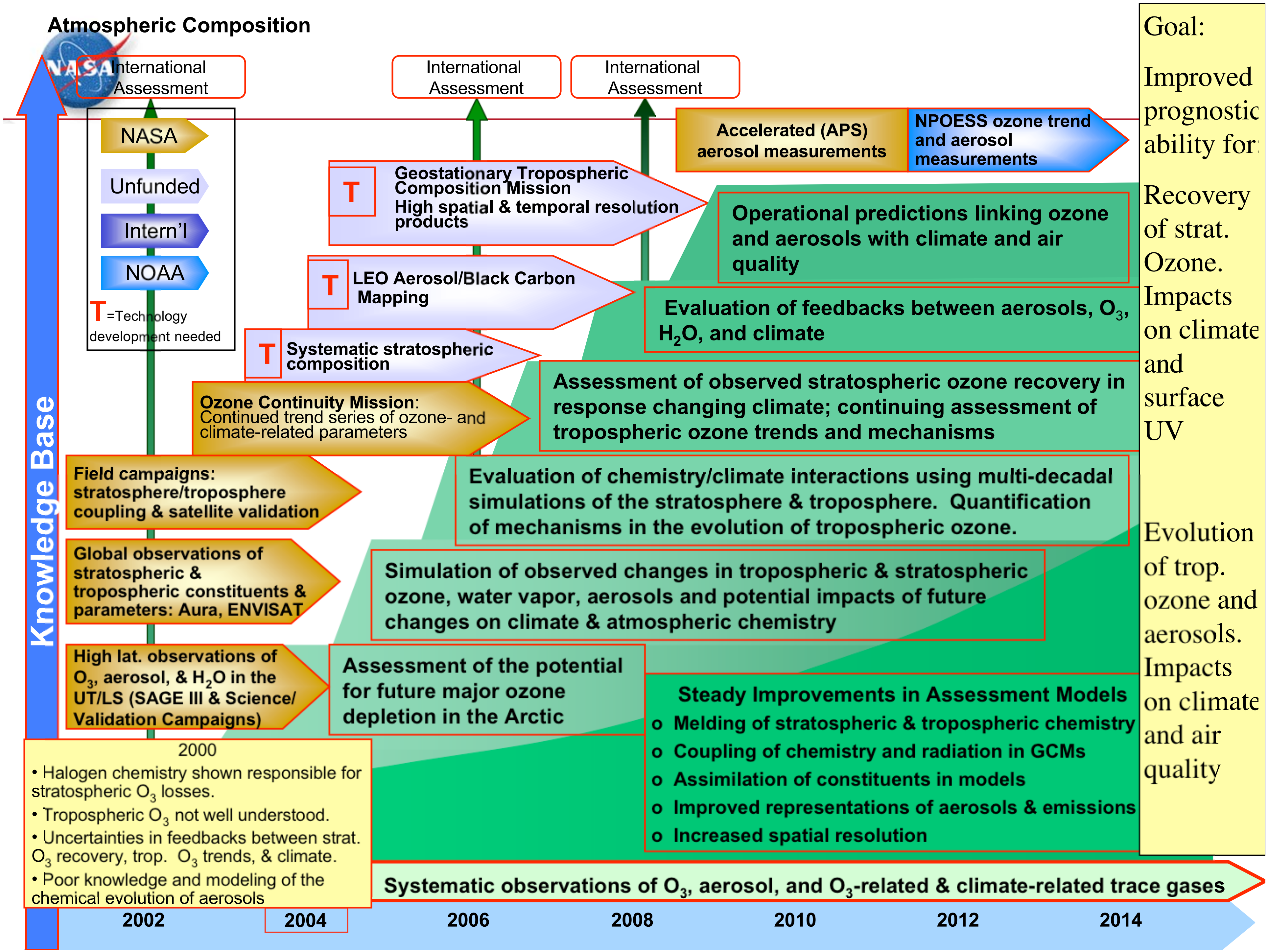
Forward

Where we are now	Where we plan to be
Large uncertainties in tropospheric aerosol forcing. Good knowledge of greenhouse gases and their corresponding forcing.	Precise knowledge of greenhouse gases forcings and feedbacks (sea ice, water vapor etc.). Good knowledge of tropospheric aerosol forcing and cloud effects.
Climate models simulate long-term global temperature change with large uncertainty in forcings and sensitivity.	Comprehensive earth system models capable of simulating future climate changes based on different forcing scenarios with good confidence.
6-9 month forecasts of global surface temperatures and precipitation are conducted routinely	Routine operational integrated modeling and forecasting system for seasonal-to-interannual predictions using multiple satellite and *in situ* data streams.
Insufficient knowledge and representation of processes such as upwelling and surface heat, freshwater and the modeling of low level clouds	Enhanced global satellite observations of surface winds, heat, freshwater, radiation and vertical distribution of clouds and temperature to improve modeling of air-sea exchange and low-level clouds
Limited knowledge of partitioning of sea level rise including uncertainty of whether ice sheets are growing or shrinking	Decadal ice sheet mass balance estimates, improved assessment of contributions from glaciers and ocean thermal expansion with greatly enhanced sea level prediction capabilities
2002	~ 2015

Roadmap

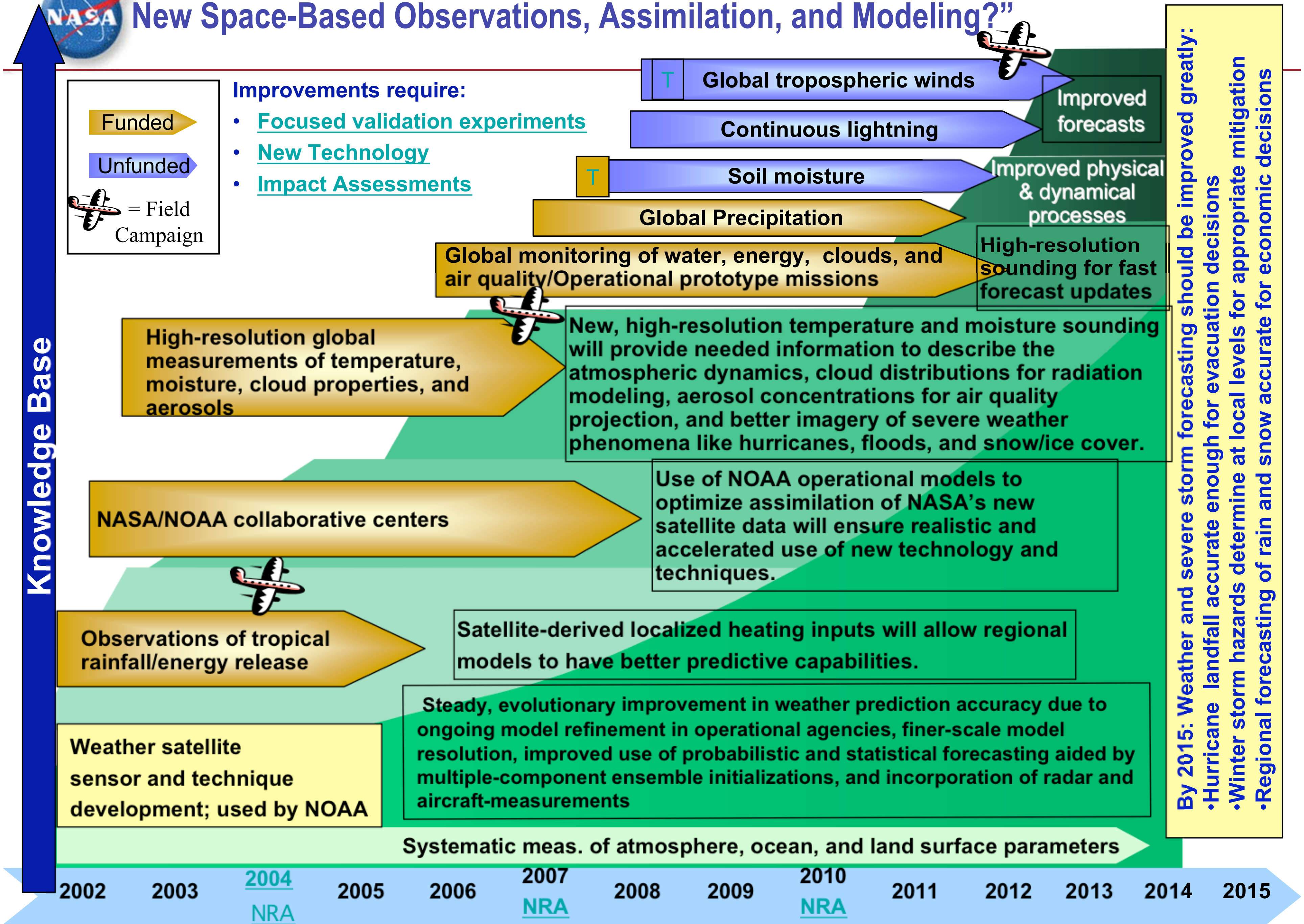
Anticipated Outcomes and Uses of Climate Models: Predicting Future Climate Variability and Change

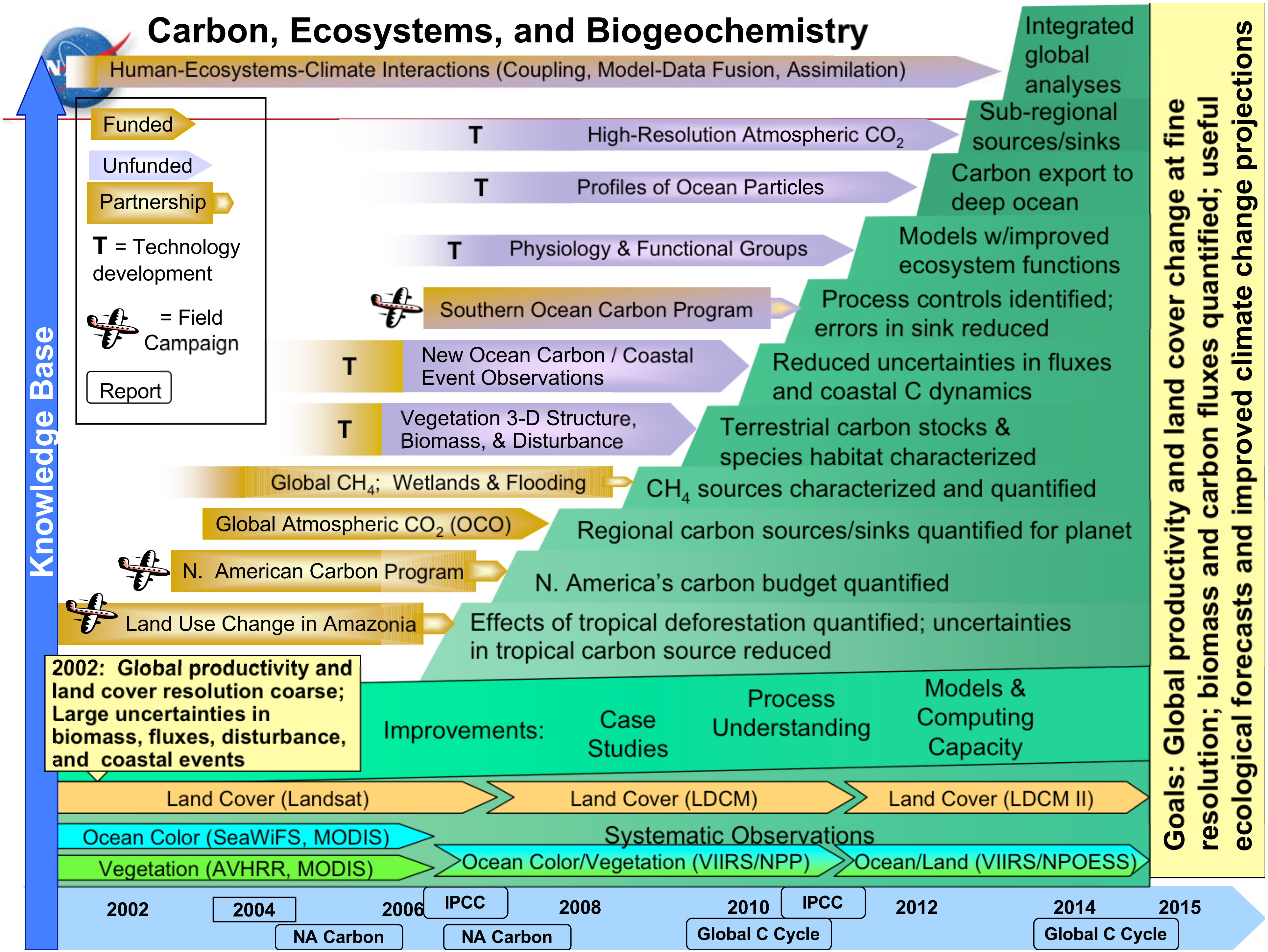
Model Capability	Products / Uses for Decision Support
Comprehensive earth system models capable of simulating future climate changes based on different forcing scenarios with good confidence.	Quantitative options for reducing climate forcings provided to policy and management decision makers.
Integrated modeling and forecasting system for seasonal-to-interannual predictions using multiple satellite and *in situ* data streams.	Forecasts of risk of extreme events or prolonged wet or dry conditions.
Climate models that: - Reliably characterize regional effects of global climate change - Provide quantitative evaluation of climate sensitivity - Provide sources of prediction skill globally	Projections of changes in the climate system with sub-regional specificity and good reliability. -- Credible, useful analyses of climate forcings and feedbacks for a variety of policy-relevant "what if" scenarios.
Regional sea level rise prediction capability	Information for coastal planning and management



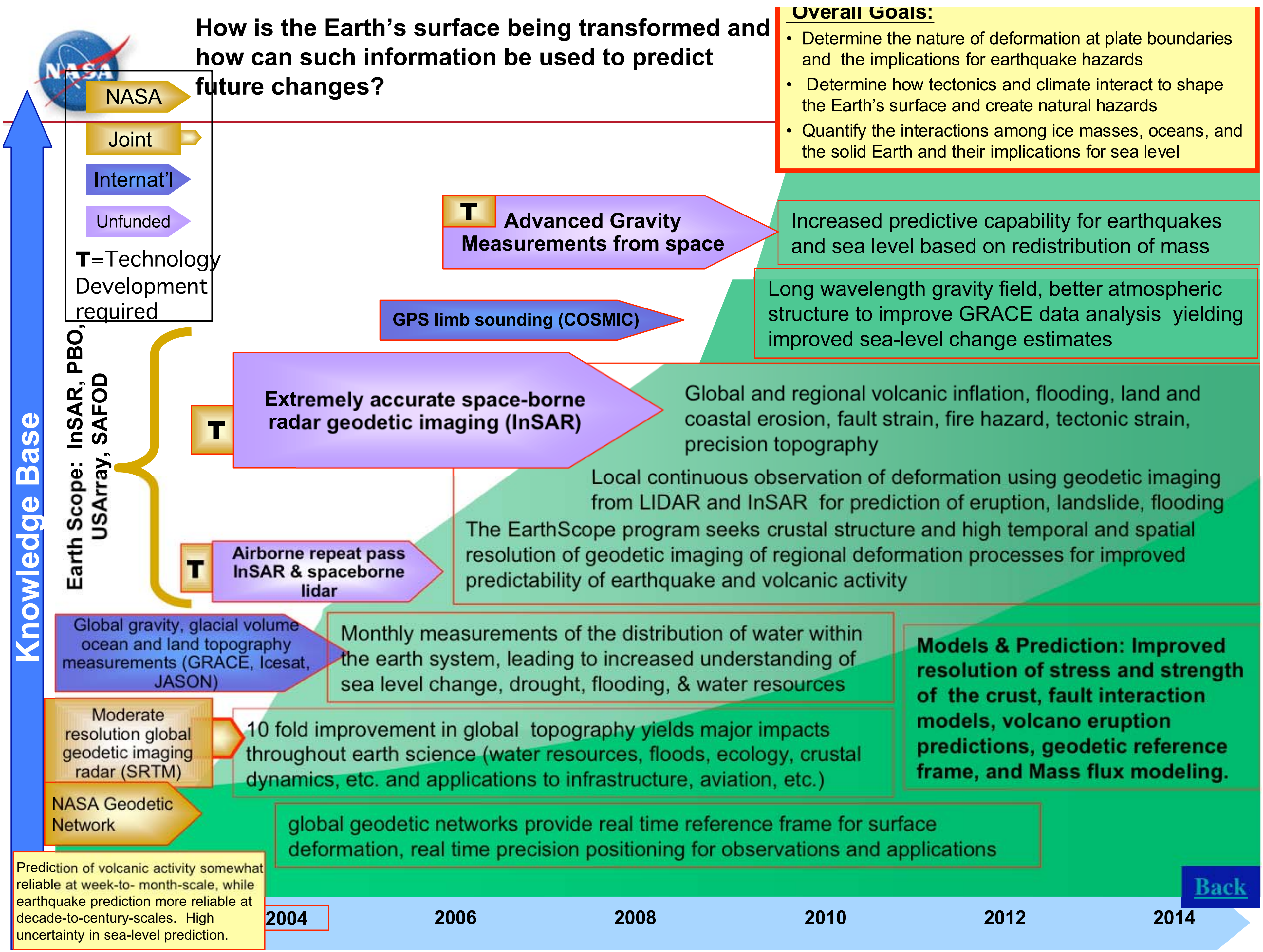
Atmospheric Composition
International Assessment
International Assessment
International Assessment
NASA
Unfunded
Intern'l
NOAA
T =Technology development needed
Knowledge Base
Accelerated (APS) aerosol measurements
NPOESS ozone trend and aerosol measurements
T Geostationary Tropospheric Composition Mission
High spatial & temporal resolution products
T LEO Aerosol/Black Carbon Mapping
T Systematic stratospheric composition
Ozone Continuity Mission: Continued trend series of ozone- and climate-related parameters
Field campaigns: stratosphere/troposphere coupling & satellite validation
Global observations of stratospheric & tropospheric constituents & parameters: Aura, ENVISAT
High lat. observations of O_3, aerosol, & H_2O in the UT/LS (SAGE III & Science/ Validation Campaigns)
Operational predictions linking ozone and aerosols with climate and air quality
Evaluation of feedbacks between aerosols, O_3, H_2O, and climate
Assessment of observed stratospheric ozone recovery in response changing climate; continuing assessment of tropospheric ozone trends and mechanisms
Evaluation of chemistry/climate interactions using multi-decadal simulations of the stratosphere & troposphere. Quantification of mechanisms in the evolution of tropospheric ozone.
Simulation of observed changes in tropospheric & stratospheric ozone, water vapor, aerosols and potential impacts of future changes on climate & atmospheric chemistry
Assessment of the potential for future major ozone depletion in the Arctic
Steady Improvements in Assessment Models
o Melding of stratospheric & tropospheric chemistry
o Coupling of chemistry and radiation in GCMs
o Assimilation of constituents in models
o Improved representations of aerosols & emissions
o Increased spatial resolution
2000
• Halogen chemistry shown responsible for stratospheric O_3 losses.
• Tropospheric O_3 not well understood.
• Uncertainties in feedbacks between strat. O_3 recovery, trop. O_3 trends, & climate.
• Poor knowledge and modeling of the chemical evolution of aerosols
Systematic observations of O_3, aerosol, and O_3-related & climate-related trace gases
2002
2004
2006
2008
2010
2012
2014
Goal:
Improved prognostic ability for:
Recovery of strat. Ozone. Impacts on climate and surface UV
Evolution of trop. ozone and aerosols. Impacts on climate and air quality

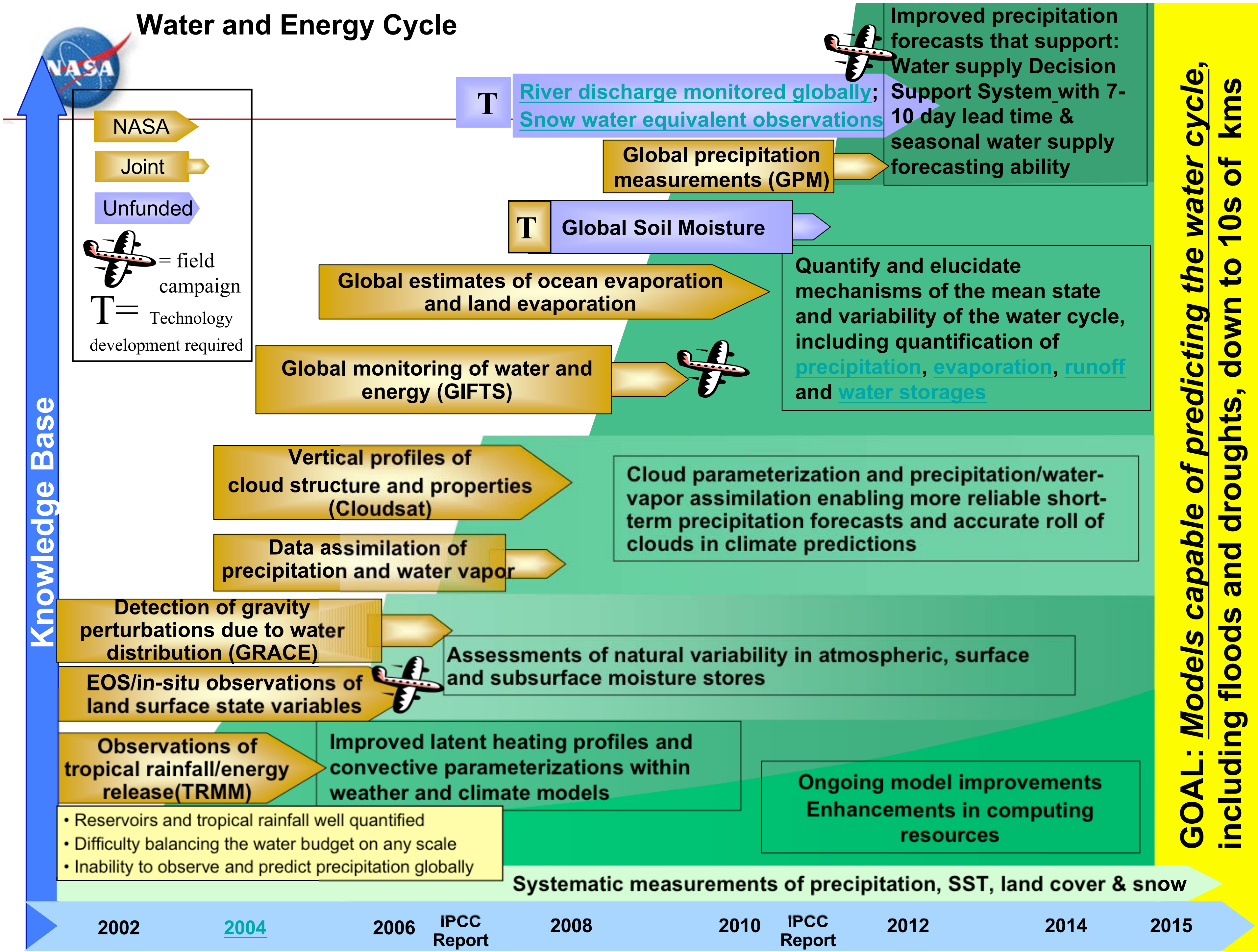
"How Can Weather Forecast Duration and Reliability Be Improved By New Space-Based Observations, Assimilation, and Modeling?"



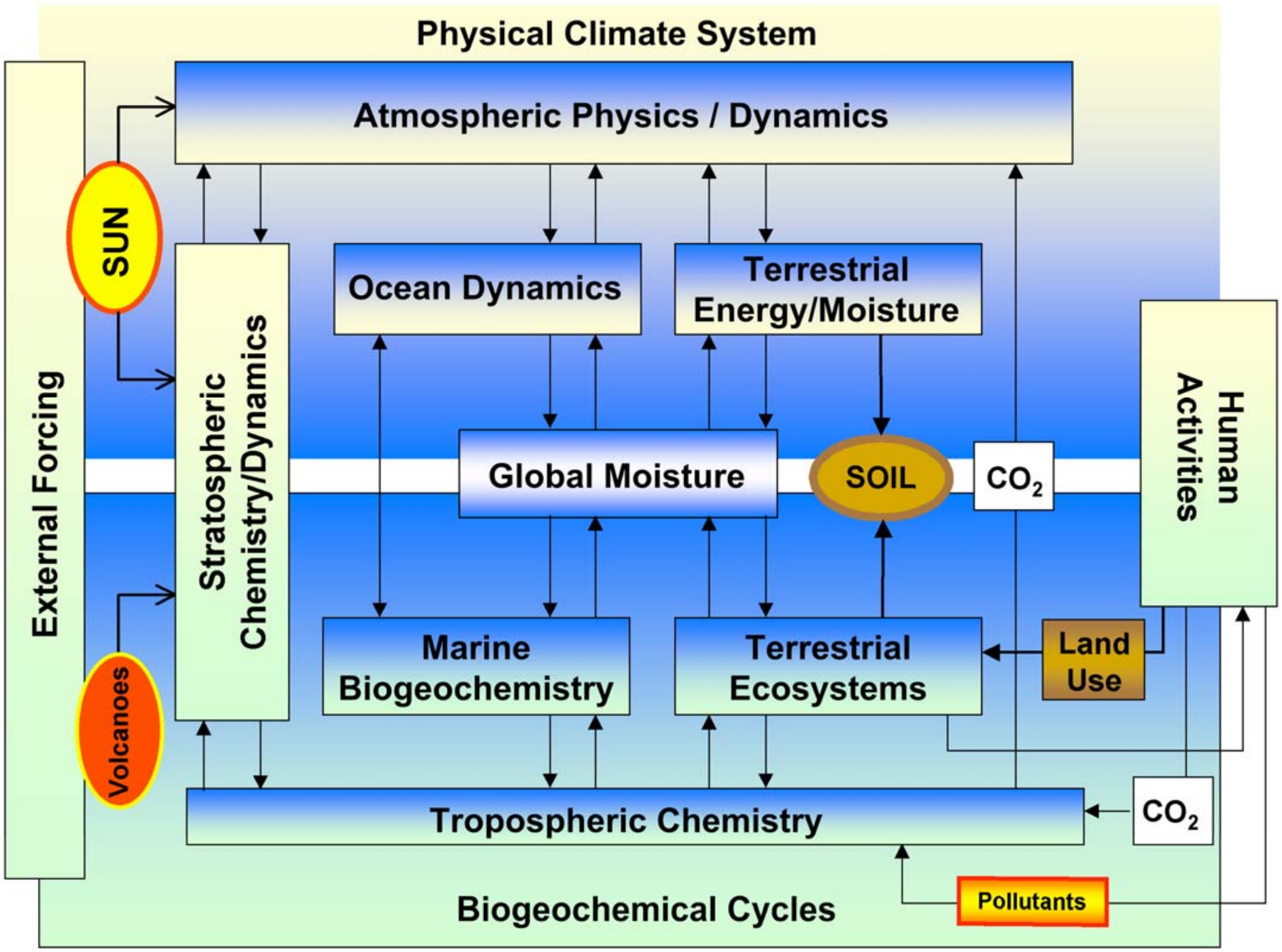


Carbon, Ecosystems, and Biogeochemistry
Human-Ecosystems-Climate Interactions (Coupling, Model-Data Fusion, Assimilation)
Funded
Unfunded
Partnership
T = Technology development
= Field Campaign
Report
T High-Resolution Atmospheric CO_2
T Profiles of Ocean Particles
T Physiology & Functional Groups
Southern Ocean Carbon Program
T New Ocean Carbon / Coastal Event Observations
T Vegetation 3-D Structure, Biomass, & Disturbance
Global CH_4; Wetlands & Flooding
Global Atmospheric CO_2 (OCO)
N. American Carbon Program
Land Use Change in Amazonia
Integrated global analyses
Sub-regional sources/sinks
Carbon export to deep ocean
Models w/improved ecosystem functions
Process controls identified; errors in sink reduced
Reduced uncertainties in fluxes and coastal C dynamics
Terrestrial carbon stocks & species habitat characterized
CH_4 sources characterized and quantified
Regional carbon sources/sinks quantified for planet
N. America's carbon budget quantified
Effects of tropical deforestation quantified; uncertainties in tropical carbon source reduced
2002: Global productivity and land cover resolution coarse; Large uncertainties in biomass, fluxes, disturbance, and coastal events
Improvements:
Case Studies
Process Understanding
Models & Computing Capacity
Land Cover (Landsat)
Land Cover (LDCM)
Land Cover (LDCM II)
Systematic Observations
Ocean Color (SeaWiFS, MODIS)
Vegetation (AVHRR, MODIS)
Ocean Color/Vegetation (VIIRS/NPP)
Ocean/Land (VIIRS/NPOESS)
Knowledge Base
2002
2004
2006
IPCC
2008
2010
IPCC
2012
2014
2015
NA Carbon
NA Carbon
Global C Cycle
Global C Cycle
Goals: Global productivity and land cover change at fine resolution; biomass and carbon fluxes quantified; useful ecological forecasts and improved climate change projections


How is the Earth's surface being transformed and how can such information be used to predict future changes?
Overall Goals:
• Determine the nature of deformation at plate boundaries and the implications for earthquake hazards
• Determine how tectonics and climate interact to shape the Earth's surface and create natural hazards
• Quantify the interactions among ice masses, oceans, and the solid Earth and their implications for sea level
NASA
Joint
Internat'l
Unfunded
T=Technology Development required
Knowledge Base
Earth Scope: InSAR, PBO, USArray, SAFOD
T
Advanced Gravity Measurements from space
Increased predictive capability for earthquakes and sea level based on redistribution of mass
GPS limb sounding (COSMIC)
Long wavelength gravity field, better atmospheric structure to improve GRACE data analysis yielding improved sea-level change estimates
T
Extremely accurate space-borne radar geodetic imaging (InSAR)
Global and regional volcanic inflation, flooding, land and coastal erosion, fault strain, fire hazard, tectonic strain, precision topography
Local continuous observation of deformation using geodetic imaging from LIDAR and InSAR for prediction of eruption, landslide, flooding
T
Airborne repeat pass InSAR & spaceborne lidar
The EarthScope program seeks crustal structure and high temporal and spatial resolution of geodetic imaging of regional deformation processes for improved predictability of earthquake and volcanic activity
Global gravity, glacial volume ocean and land topography measurements (GRACE, Icesat, JASON)
Monthly measurements of the distribution of water within the earth system, leading to increased understanding of sea level change, drought, flooding, & water resources
Models & Prediction: Improved resolution of stress and strength of the crust, fault interaction models, volcano eruption predictions, geodetic reference frame, and Mass flux modeling.
Moderate resolution global geodetic imaging radar (SRTM)
10 fold improvement in global topography yields major impacts throughout earth science (water resources, floods, ecology, crustal dynamics, etc. and applications to infrastructure, aviation, etc.)
NASA Geodetic Network
global geodetic networks provide real time reference frame for surface deformation, real time precision positioning for observations and applications
Prediction of volcanic activity somewhat reliable at week-to- month-scale, while earthquake prediction more reliable at decade-to-century-scales. High uncertainty in sea-level prediction.
2004
2006
2008
2010
2012
2014
Back



Water and Energy Cycle
NASA
Joint
Unfunded
= field campaign
T= Technology development required
Knowledge Base
T
River discharge monitored globally; Snow water equivalent observations
Improved precipitation forecasts that support: Water supply Decision Support System with 7-10 day lead time & seasonal water supply forecasting ability
Global precipitation measurements (GPM)
T
Global Soil Moisture
Global estimates of ocean evaporation and land evaporation
Quantify and elucidate mechanisms of the mean state and variability of the water cycle, including quantification of precipitation, evaporation, runoff and water storages
Global monitoring of water and energy (GIFTS)
Vertical profiles of cloud structure and properties (Cloudsat)
Cloud parameterization and precipitation/water-vapor assimilation enabling more reliable short-term precipitation forecasts and accurate roll of clouds in climate predictions
Data assimilation of precipitation and water vapor
Detection of gravity perturbations due to water distribution (GRACE)
Assessments of natural variability in atmospheric, surface and subsurface moisture stores
EOS/in-situ observations of land surface state variables
Observations of tropical rainfall/energy release(TRMM)
Improved latent heating profiles and convective parameterizations within weather and climate models
Ongoing model improvements Enhancements in computing resources
• Reservoirs and tropical rainfall well quantified
• Difficulty balancing the water budget on any scale
• Inability to observe and predict precipitation globally
Systematic measurements of precipitation, SST, land cover & snow
2002
2004
2006
IPCC Report
2008
2010
IPCC Report
2012
2014
2015
GOAL: Models capable of predicting the water cycle, including floods and droughts, down to 10s of kms



Physical Climate System
Atmospheric Physics / Dynamics
External Forcing
SUN
Volcanoes
Stratospheric Chemistry/Dynamics
Ocean Dynamics
Terrestrial Energy/Moisture
Global Moisture
SOIL
CO_2
Human Activities
Marine Biogeochemistry
Terrestrial Ecosystems
Land Use
Tropospheric Chemistry
CO_2
Pollutants
Biogeochemical Cycles